2019

Engineering of bio-mimetic substratum topographies for enhanced early colonization of filamentous algae

Ali Khoshkhoo
Binghamton University, khoshkho@binghamton.edu

Andres L. Carrano
Georgia Southern University, acarrano@georgiasouthern.edu

David M. Blersch
Auburn University, dmb0040@auburn.edu

2019

Engineering of bio-mimetic substratum topographies for enhanced early colonization of filamentous algae

Ali Khoshkhoo

Andres L. Carrano

David M. Blersch

Kamran Kardel

Log data for surface texture and significant features' (dales) parameters of colonized and non-colonized areas

Type of parameter	Parameter	Description	Mean colonized	σ colonized	Mean non-colonized	σ non-colonized	p-value
Feature Parameters	S_{10z} *(µm)*	ten-point height of the surface	430.9	95.9	441.9	174.8	0.633
	S_{5v} *(µm)*	five-point pit height of the surface	217.7	50.2	234.9	127.3	0.832
Height Parameters	S_q *(µm)*	root mean square height	59.2	15.8	50.3	17.0	0.085
	S_{sk}	skewness	-0.2	0.5	-0.3	0.4	0.663
	S_{ku}	kurtosis	2.7	0.3	2.8	0.5	0.581
	S_p *(µm)*	maximum peak height	207.2	91.3	192.6	75.6	0.542
	S_v *(µm)*	maximum pit height	203.9	49.1	163.6	55.8	0.015
	S_z *(µm)*	maximum height of the surface	424.9	114.8	367.4	147.3	0.136
	S_a *(µm)*	arithmetical mean of the absolute of the ordinate values	46.6	12.0	38.2	10.9	0.026
Functional Parameters	S_{mr} *(%)*	areal material ratio	0.0008	0.0007	0.0040	0.0020	0.000
	S_{mc} *(µm)*	inverse areal material ratio	87.8	41.3	104.7	55.2	0.224
	S_{xp} *(µm)*	peak extreme height	133.0	49.1	115.4	46.5	0.222
Spatial Parameters	S_{al} *(mm)*	autocorrelation length	0.8	0.4	8.7	41.6	0.410
	S_{tr}	texture aspect ratio	0.5	0.2	0.4	0.2	0.150
	S_{td} °	texture direction of the scale-limited surface	87.3	63.1	97.9	66.9	0.112
Functional Parameters (Volume)	V_m *(mm³/mm²)*	material volume	0.01	0.01	0.1	0.2	0.383
	V_v *(mm³/mm²)*	void volume	0.09	0.03	2.2	10.9	0.392
	V_{mp} *(mm³/mm²)*	peak material volume	0.01	0.01	0.04	0.2	0.382
	V_{mc} *(mm³/mm²)*	core material volume	0.06	0.02	1.7	8.3	0.361
	V_{vc} *(mm³/mm²)*	core void volume	0.08	0.03	2.1	10.3	0.424
	V_{vv} *(mm³/mm²)*	dale void volume	0.01	0.00	0.12	0.6	0.383
	S_k *(µm)*	core height	40.9	16.6	44.3	23.8	0.582

Functional Parameters (Stratified surfaces)	S_{pk} *(µm)*	reduced peak height	15.2	5.8	14.9	9.9	0.931
	S_{vk} *(µm)*	reduced dale height	29.5	13.3	29.4	16.1	0.972
	S_{mr1} *(%)*	(peaks) ratio of the area of the material at the intersection line	8.8	2.1	8.2	1.9	0.102
	S_{mr2} *(%)*	(dales) ratio of the area of the material at the intersection line	86.5	3.7	86.1	3.2	0.68

Log data from biomass measurement

	Level 1		
	Sample	Dried biomass-level 1 (gr)	(mg/cm^2)
Trial 1	1_1	0.0149	0.596
	2_1	0.0098	0.392
	3_1	0.0133	0.532
	4_1	0.0142	0.568
	5_1	0.0112	0.448
	6_1	0.016	0.64
	7_1	0.0123	0.492
	8_1	0.0083	0.332
	9_1	0.0184	0.736
	10_1	0.0122	0.488
	11_1	0.0096	0.384
	12_1	0.0154	0.616
Trial 2	1_1	0.0065	0.26
	2_1	0.0101	0.404
	3_1	0.0128	0.512
	4_1	0.0092	0.368
	5_1	0.0072	0.288
	6_1	0.013	0.52
	7_1	0.0069	0.276
	8_1	0.0051	0.204
	9_1	0.0062	0.248
	10_1	0.0127	0.508
	11_1	0.0158	0.632
	12_1	0.0056	0.224
Trial 3	1_1	0.0123	0.492
	2_1	0.0141	0.564
	3_1	0.0138	0.552

4_1	0.0116	0.464
5_1	0.0126	0.504
6_1	0.0159	0.636
7_1	0.0211	0.844
8_1	0.0144	0.576
9_1	0.0174	0.696
10_1	0.0202	0.808
11_1	0.0171	0.684
12_1	0.0187	0.748
Average	0.0127	0.5065556
STD	0.0041	0.1658258
Max	0.0211	0.844
Min	0.0051	0.204
Median	0.01275	0.51

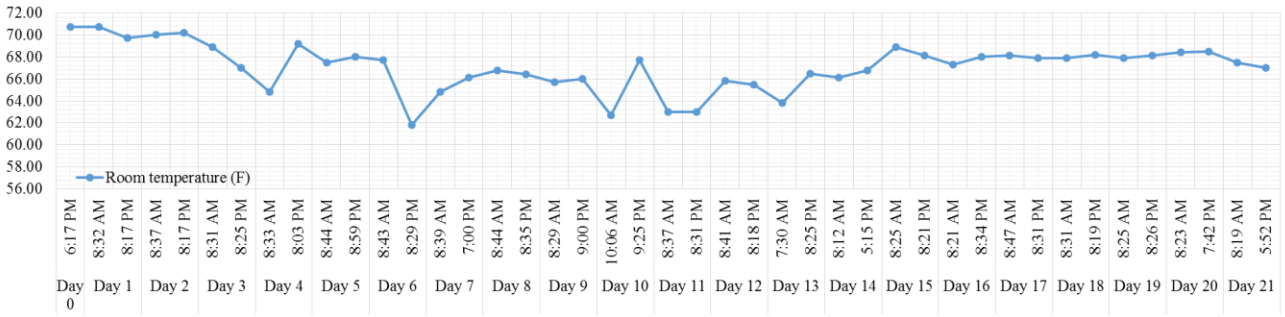
	Level 2		
	Sample	Dried biomass-level 2	(mg/cm^2)
Trial 1	1_1	0.0361	1.444
	2_1	0.0339	1.356
	3_1	0.0434	1.736
	4_1	0.0415	1.66
	5_1	0.0358	1.432
	6_1	0.0354	1.416
	7_1	0.0552	2.208
	8_1	0.0495	1.98
	9_1	0.0465	1.86
	10_1	0.0663	2.652
	11_1	0.0431	1.724
	12_1	0.0532	2.128
Trial 2	1_1	0.0401	1.604
	2_1	0.0314	1.256
	3_1	0.0541	2.164
	4_1	0.0465	1.86
	5_1	0.0292	1.168
	6_1	0.0393	1.572
	7_1	0.0646	2.584
	8_1	0.04	1.6
	9_1	0.0389	1.556
	10_1	0.056	2.24
	11_1	0.038	1.52
	12_1	0.0416	1.664
Trial 3	1_1	0.0474	1.896
	2_1	0.0454	1.816

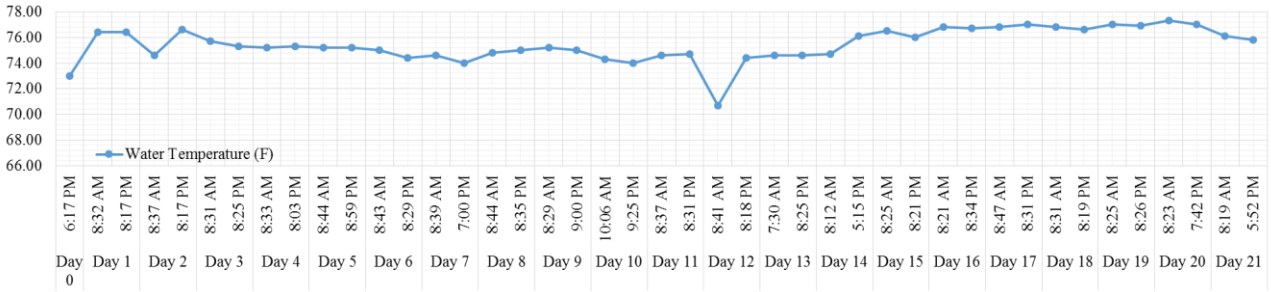
	3_1	0.0514	2.056
	4_1	0.0543	2.172
	5_1	0.0543	2.172
	6_1	0.0504	2.016
	7_1	0.0398	1.592
	8_1	0.0584	2.336
	9_1	0.0572	2.288
	10_1	0.0698	2.792
	11_1	0.0523	2.092
	12_1	0.0363	1.452
Average		0.0466	1.862889
STD		0.0100	0.400496
Max		0.0698	2.792
Min		0.0292	1.168
Median		0.04595	1.838

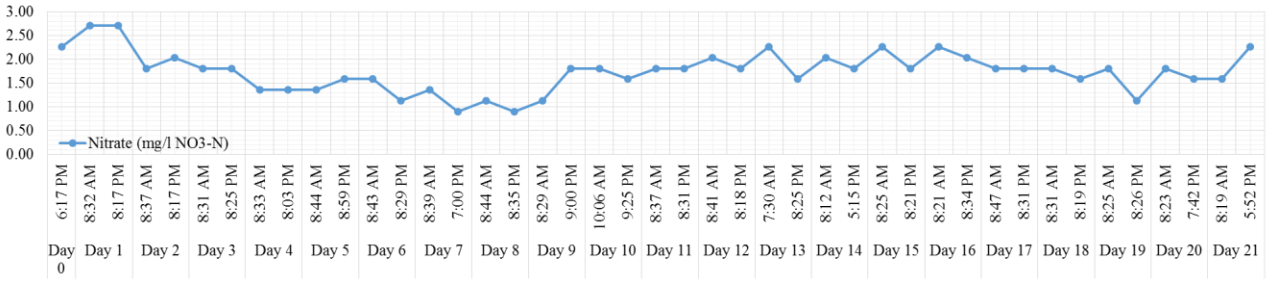
Log data from bioreactor

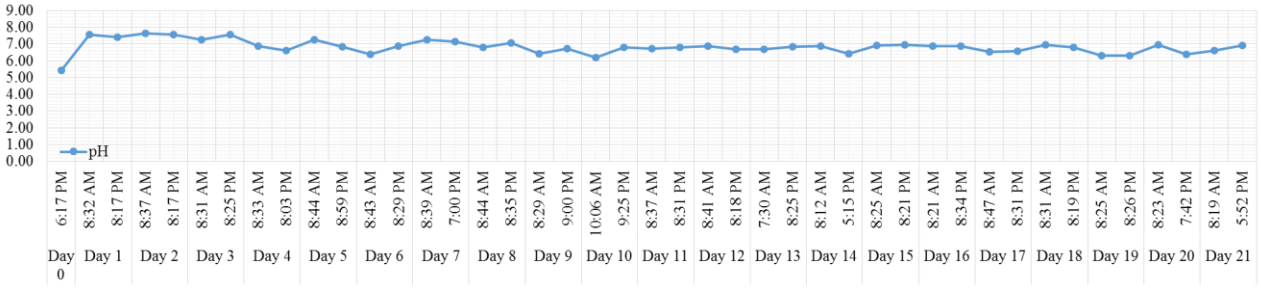
Date	Time	Room temperature (F)	Water Temperature (F)	pH	Conductivity	Nitrate (mg/l NO3^-)	Nitrate (mg/l NO3-N)	Comments
12/3/2017	6:17 PM	70.70	73.00	5.42	0.03	10.00	2.26	Trial 1
12/4/2017	8:32 AM	70.70	76.40	7.57	0.03	12.00	2.71	
	8:17 PM	69.70	76.40	7.42	0.03	12.00	2.71	
12/5/2017	8:37 AM	70.00	74.60	7.63	0.02	8.00	1.81	
	8:17 PM	70.20	76.60	7.55	0.03	9.00	2.03	
12/6/2017	8:31 AM	68.90	75.70	7.26	0.03	8.00	1.81	
	8:25 PM	67.00	75.30	7.57	0.03	8.00	1.81	
12/7/2017	8:33 AM	64.80	75.20	6.89	0.03	6.00	1.36	
	8:03 PM	69.20	75.30	6.60	0.03	6.00	1.36	
12/8/2017	8:44 AM	67.50	75.20	7.24	0.03	6.00	1.36	
	8:59 PM	68.00	75.20	6.85	0.03	7.00	1.58	
12/9/2017	8:43 AM	67.70	75.00	6.40	0.03	7.00	1.58	
	8:29 PM	61.80	74.40	6.86	0.03	5.00	1.13	
12/10/2017	8:39 AM	64.80	74.60	7.24	0.03	6.00	1.36	
	7:00 PM	66.10	74.00	7.16	0.03	4.00	0.90	Trial 2
12/11/2017	8:44 AM	66.80	74.80	6.80	0.03	5.00	1.13	
	8:35 PM	66.40	75.00	7.05	0.03	4.00	0.90	
12/12/2017	8:29 AM	65.70	75.20	6.42	0.03	5.00	1.13	
	9:00 PM	66.00	75.00	6.73	0.03	8.00	1.81	
12/13/2017	10:06 AM	62.70	74.30	6.20	0.03	8.00	1.81	
	9:25 PM	67.70	74.00	6.80	0.03	7.00	1.58	
12/14/2017	8:37 AM	63.00	74.60	6.72	0.03	8.00	1.81	

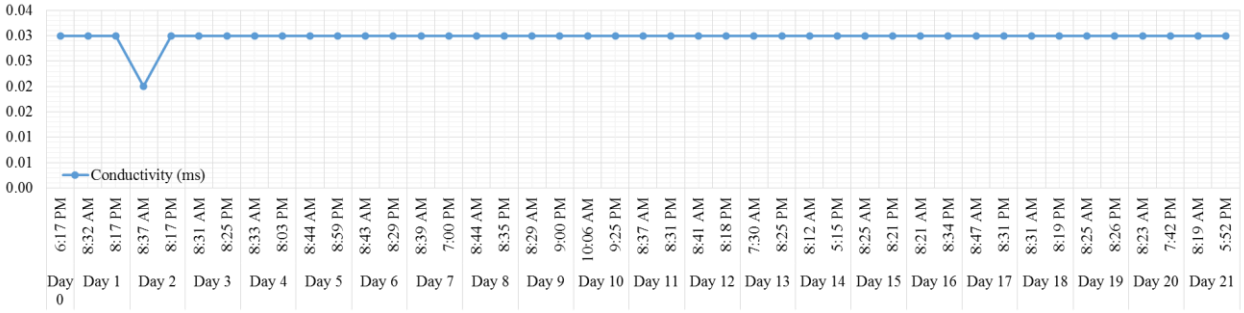
	8:31 PM	63.00	74.70	6.82	0.03	8.00	1.81	
12/15/2017	8:41 AM	65.80	70.70	6.86	0.03	9.00	2.03	
	8:18 PM	65.50	74.40	6.67	0.03	8.00	1.81	
12/16/2017	7:30 AM	63.80	74.60	6.69	0.03	10.00	2.26	
	8:25 PM	66.50	74.60	6.84	0.03	7.00	1.58	
12/17/2017	8:12 AM	66.10	74.70	6.87	0.03	9.00	2.03	
	5:15 PM	66.80	76.10	6.41	0.03	8.00	1.81	Trial 3
12/18/2017	8:25 AM	68.90	76.50	6.90	0.03	10.00	2.26	
	8:21 PM	68.10	76.00	6.96	0.03	8.00	1.81	
12/19/2017	8:21 AM	67.30	76.80	6.86	0.03	10.00	2.26	
	8:34 PM	68.00	76.70	6.87	0.03	9.00	2.03	
12/20/2017	8:47 AM	68.10	76.80	6.55	0.03	8.00	1.81	
	8:31 PM	67.90	77.00	6.58	0.03	8.00	1.81	
12/21/2017	8:31 AM	67.90	76.80	6.94	0.03	8.00	1.81	
	8:19 PM	68.20	76.60	6.81	0.03	7.00	1.58	
12/22/2017	8:25 AM	67.90	77.00	6.30	0.03	8.00	1.81	
	8:26 PM	68.10	76.90	6.30	0.03	5.00	1.13	
12/23/2017	8:23 AM	68.40	77.30	6.94	0.03	8.00	1.81	
	7:42 PM	68.50	77.00	6.38	0.03	7.00	1.58	
12/24/2017	8:19 AM	67.50	76.10	6.62	0.03	7.00	1.58	
	5:52 PM	67.00	75.80	6.93	0.03	10.00	2.26	











	Time to fill 2 litters (s)			
	Lane 1	Lane 2	Lane 3	Lane 4
Rep 1	13.980	13.560	13.510	13.500
Rep 2	13.860	13.830	13.570	13.780
Rep 3	14.130	13.680	13.730	13.400
Rep 4	13.960	13.660	13.730	13.520
Rep 5	13.880	13.530	13.910	13.450
Average	13.962	13.652	13.690	13.530
STD	0.107	0.118	0.157	0.147

	Flow rate (m^3/s)			
	Lane 1	Lane 2	Lane 3	Lane 4
Rep 1	0.0001431	0.0001475	0.0001480	0.0001481

Rep 2	0.0001443	0.0001446	0.0001474	0.0001451
Rep 3	0.0001415	0.0001462	0.0001457	0.0001493
Rep 4	0.0001433	0.0001464	0.0001457	0.0001479
Rep 5	0.0001441	0.0001478	0.0001438	0.0001487
Average	0.0001433	0.0001465	0.0001461	0.0001478
STD	0.0000011	0.0000013	0.0000017	0.0000016

	Travel time (s)			
	Lane 1	Lane 2	Lane 3	Lane 4
Rep 1	3.620	4.340	4.050	4.640
Rep 2	3.610	4.250	4.280	4.470
Rep 3	3.620	4.360	4.190	4.140
Rep 4	3.630	4.130	4.140	4.920
Rep 5	3.610	4.220	4.490	4.900
Average	3.618	4.260	4.230	4.614
STD	0.008	0.094	0.167	0.325

	Velocity (m/s)			
	Lane 1	Lane 2	Lane 3	Lane 4
Rep 1	0.334	0.281	0.299	0.263
Rep 2	0.335	0.287	0.283	0.273
Rep 3	0.334	0.280	0.289	0.295
Rep 4	0.333	0.295	0.292	0.248
Rep 5	0.335	0.289	0.269	0.249
Length (m)	1.210	1.220	1.210	1.220
Average	0.334	0.286	0.286	0.265
STD	0.001	0.006	0.011	0.019

Log data from computer model

Reps	Level 1								
	Zavg	Sa	Sq	Ssk	Sku	Sv	Sp	Sz	Smr
Rep 1	-1.62	0.74	0.92	0.98	2.81	6.68	2.83	9.51	31.67
Rep 2	-1.43	0.73	0.92	0.96	2.81	6.63	2.52	9.14	31.16
Rep 3	-1.65	0.73	0.91	0.98	2.76	6.69	2.54	9.24	30.07
Rep 4	-1.52	0.73	0.92	0.95	2.82	6.77	2.52	9.29	32.07
Rep 5	-1.66	0.74	0.93	0.93	2.85	7.16	2.75	9.91	31.06

Rep 6	-1.53	0.74	0.92	1.01	2.82	6.55	2.74	9.28	31.62
Rep 7	-1.47	0.72	0.91	0.98	2.79	6.71	2.51	9.22	29.05
Rep 8	-1.42	0.72	0.90	1.00	2.79	6.47	2.43	8.90	29.96
Rep 9	-1.56	0.71	0.89	1.05	2.77	6.35	2.56	8.91	28.88
Rep 10	-1.53	0.72	0.91	0.98	2.81	6.61	2.80	9.42	30.92
Rep 11	-1.62	0.73	0.92	0.95	2.82	6.65	2.68	9.33	31.80
Rep 12	-1.70	0.73	0.91	0.99	2.79	6.70	2.60	9.30	31.52
Rep 13	-1.42	0.72	0.90	1.00	2.79	6.47	2.43	8.90	29.96
Rep 14	-1.56	0.71	0.89	1.05	2.77	6.35	2.56	8.91	28.88
Rep 15	-1.51	0.71	0.90	1.04	2.81	6.53	2.43	8.96	28.21
Rep 16	-1.60	0.72	0.90	1.05	2.79	6.36	2.58	8.94	29.98
Rep 17	-1.65	0.73	0.91	0.98	2.76	6.69	2.54	9.24	30.07
Rep 18	-1.66	0.74	0.93	0.93	2.85	7.16	2.75	9.91	31.06
Rep 19	-1.47	0.72	0.91	0.98	2.79	6.71	2.51	9.22	29.05
Rep 20	-1.42	0.72	0.90	1.00	2.79	6.47	2.43	8.90	29.96
Rep 21	-1.56	0.71	0.89	1.05	2.77	6.35	2.56	8.91	28.88
Rep 22	-1.53	0.72	0.91	0.98	2.81	6.61	2.80	9.42	30.92
Rep 23	-1.53	0.73	0.92	0.97	2.79	6.81	2.59	9.40	31.02
Rep 24	-1.51	0.71	0.90	1.04	2.81	6.53	2.43	8.96	28.21
Rep 25	-1.65	0.73	0.91	0.98	2.76	6.69	2.54	9.24	30.07
Rep 26	-1.66	0.74	0.93	0.93	2.85	7.16	2.75	9.91	31.06
Rep 27	-1.47	0.72	0.91	0.98	2.79	6.71	2.51	9.22	29.05
Rep 28	-1.42	0.72	0.90	1.00	2.79	6.47	2.43	8.90	29.96
Rep 29	-1.56	0.71	0.89	1.05	2.77	6.35	2.56	8.91	28.88
Rep 30	-1.53	0.72	0.91	0.98	2.81	6.61	2.80	9.42	30.92
Rep 31	-1.51	0.71	0.90	1.04	2.81	6.53	2.43	8.96	28.21
Rep 32	-1.65	0.73	0.91	0.98	2.76	6.69	2.54	9.24	30.07
Rep 33	-1.66	0.74	0.93	0.93	2.85	7.16	2.75	9.91	31.06
Rep 34	-1.47	0.72	0.91	0.98	2.79	6.71	2.51	9.22	29.05
Rep 35	-1.51	0.71	0.90	1.04	2.81	6.53	2.43	8.96	28.21
Rep 36	-1.56	0.71	0.89	1.05	2.77	6.35	2.56	8.91	28.88
Average	-1.55	0.72	0.91	0.99	2.80	6.64	2.58	9.22	30.04
STD	0.083563	0.01	0.011313	0.037362	0.025987	0.23	0.128491	0.31066	1.16
CV (%)	5.40	1.35	1.24	3.76	0.93	3.44	4.98	3.37	3.87
Min	-1.70	0.71	0.89	0.93	2.76	6.35	2.43	8.90	28.21
Max	-1.42	0.74	0.93	1.05	2.85	7.16	2.83	9.91	32.07

Reps	Level 2								
	Zavg	Sa	Sq	Ssk	Sku	Sv	Sp	Sz	Smr
Rep 1	-1.92	2.17	2.74	-0.09	3.00	8.84	9.71	18.56	51.86
Rep 2	-0.84	2.03	2.52	-0.23	2.78	7.78	7.62	15.40	52.72
Rep 3	-1.10	2.18	2.73	-0.25	3.20	10.34	8.44	18.78	50.90
Rep 4	-2.19	1.89	2.38	-0.13	2.91	8.17	7.81	15.97	50.84
Rep 5	-0.72	2.07	2.54	0.00	2.60	7.97	8.03	16.01	50.65
Rep 6	-1.39	2.07	2.57	-0.13	2.84	8.67	7.66	16.33	50.88
Rep 7	-1.67	2.41	2.96	-0.20	2.68	9.58	8.45	18.03	52.25
Rep 8	-0.95	2.12	2.62	-0.06	2.57	6.90	8.21	15.10	51.68
Rep 9	-1.08	1.87	2.35	-0.26	2.93	8.31	7.56	15.87	53.75
Rep 10	-1.35	2.28	2.87	-0.02	3.07	8.91	9.62	18.53	50.74
Rep 11	-1.89	2.24	2.78	0.06	2.76	8.33	9.00	17.34	50.54
Rep 12	-1.41	2.12	2.63	-0.13	2.72	8.10	7.77	15.87	51.52
Rep 13	-1.92	2.17	2.74	-0.09	3.00	8.84	9.71	18.56	51.86
Rep 14	-0.84	2.03	2.52	-0.23	2.78	7.78	7.62	15.40	52.72
Rep 15	-1.10	2.18	2.73	-0.25	3.20	10.34	8.44	18.78	50.90
Rep 16	-2.19	1.89	2.38	-0.13	2.91	8.17	7.81	15.97	50.84
Rep 17	-0.72	2.07	2.54	0.00	2.60	7.97	8.03	16.01	50.65
Rep 18	-1.39	2.07	2.57	-0.13	2.84	8.67	7.66	16.33	50.88
Rep 19	-1.67	2.41	2.96	-0.20	2.68	9.58	8.45	18.03	52.25
Rep 20	-0.95	2.12	2.62	-0.06	2.57	6.90	8.21	15.10	51.68
Rep 21	-1.08	1.87	2.35	-0.26	2.93	8.31	7.56	15.87	53.75
Rep 22	-1.35	2.28	2.87	-0.02	3.07	8.91	9.62	18.53	50.74
Rep 23	-1.89	2.24	2.78	0.06	2.76	8.33	9.00	17.34	50.54
Rep 24	-1.41	2.12	2.63	-0.13	2.72	8.10	7.77	15.87	51.52
Rep 25	-1.92	2.17	2.74	-0.09	3.00	8.84	9.71	18.56	51.86
Rep 26	-0.84	2.03	2.52	-0.23	2.78	7.78	7.62	15.40	52.72
Rep 27	-1.67	2.41	2.96	-0.20	2.68	9.58	8.45	18.03	52.25
Rep 28	-0.95	2.12	2.62	-0.06	2.57	6.90	8.21	15.10	51.68
Rep 29	-1.08	1.87	2.35	-0.26	2.93	8.31	7.56	15.87	53.75
Rep 30	-1.41	2.12	2.63	-0.13	2.72	8.10	7.77	15.87	51.52
Rep 31	-0.77	1.88	2.32	-0.16	2.69	6.81	7.10	13.90	51.44
Rep 32	-2.02	2.04	2.55	-0.19	2.78	7.94	8.65	16.59	52.57
Rep 33	-1.61	2.34	2.89	-0.31	2.71	8.36	8.18	16.54	53.05
Rep 34	-0.98	2.33	2.91	-0.15	2.86	8.67	10.06	18.73	52.43
Rep 35	-1.65	1.98	2.52	-0.15	3.16	8.24	8.28	16.52	51.21
Rep 36	-1.31	1.81	2.23	-0.14	2.73	7.17	7.10	14.26	51.23
Average	-1.37	2.11	2.63	-0.14	2.82	8.35	8.29	16.64	51.73
STD	0.439486	0.16	0.199729	0.093453	0.17743	0.86	0.793722	1.402544	0.94

CV (%)	32.12	7.74	7.60	67.55	6.28	10.33	9.57	8.43	1.82
Min	-2.19	1.81	2.23	-0.31	2.57	6.81	7.10	13.90	50.54
Max	-0.72	2.41	2.96	0.06	3.20	10.34	10.06	18.78	53.75